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## INTERNATIONAL APPLICATION PUBLISHED UNDER THE PATENT COOPERATION TREATY (PCT)

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<p>(21) International Application Number: PCT/AU98/00575</p> <p>(22) International Filing Date: 21 July 1998 (21.07.98)</p> <p>(30) Priority Data: PO 8171 23 July 1997 (23.07.97) AU</p> <p>(71) Applicant (for all designated States except US): BISHOP INNOVATION PTY. LIMITED [AU/AU]; 10 Waterloo Road, North Ryde, NSW 2113 (AU).</p> <p>(72) Inventor; and (75) Inventor/Applicant (for US only): EISENHAUER, Karl, Yarnos [GB/AU]; 37 Easton Road, Berowra Heights, NSW 2082 (AU).</p> <p>(74) Agent: BISHOP INNOVATION PTY. LIMITED; 10 Waterloo Road, P.O. Box 135, North Ryde, NSW 2113 (AU).</p>		<p>(81) Designated States: AL, AM, AT, AU, AZ, BA, BB, BG, BR, BY, CA, CH, CN, CU, CZ, DE, DK, EE, ES, FI, GB, GE, GH, GM, HR, HU, ID, IL, IS, JP, KE, KG, KP, KR, KZ, LC, LK, LR, LS, LT, LU, LV, MD, MG, MK, MN, MW, MX, NO, NZ, PL, PT, RO, RU, SD, SE, SG, SI, SK, SL, TJ, TM, TR, TT, UA, UG, US, UZ, VN, YU, ZW, ARIPO patent (GH, GM, KE, LS, MW, SD, SZ, UG, ZW), Eurasian patent (AM, AZ, BY, KG, KZ, MD, RU, TJ, TM), European patent (AT, BE, CH, CY, DE, DK, ES, FI, FR, GB, GR, IE, IT, LU, MC, NL, PT, SE), OAPI patent (BF, BJ, CF, CG, CI, CM, GA, GN, GW, ML, MR, NE, SN, TD, TG).</p> <p><b>Published</b> With international search report.</p>
<p>(54) Title: TRANSDUCER FOR MEASURING TORQUE IN A ROTATING SHAFT</p>		
<p>(57) Abstract</p> <p>A transducer for measuring torque in a rotating shaft at least partially surrounded by a fixed housing. The transducer comprises an optical displacement sensing means, an optical transmission means, and an optical-electric converter means. The optical displacement sensing means residing on the shaft and modulating a light signal input to provide a light signal output relating to the magnitude of torque. The light signal output communicated to the optical-electric converter means via the optical transmission means. The optical transmission means comprising an optical clock spring, the optical-electric converter means either mounted to the housing or external to the housing. The optical clock spring comprising one or more flexible fiber optical cables, each cable arranged to be of sufficient length to allow the measurement of the magnitude of torque over a predetermined angular range of rotation of the shaft and the optical-electric converter means thereby providing an electrical output signal relating to the magnitude of the torque in the shaft.</p>		

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## TRANSDUCER FOR MEASURING TORQUE IN A ROTATING SHAFT

## TECHNICAL FIELD

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This invention relates to torque transducers for measuring the magnitude of torque in shafts, in particular rotating shafts such as found in electric power steering systems in vehicle applications.

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## BACKGROUND

Electric power steering systems conventionally incorporate an input shaft element, connected via an intermediate shaft and Hookes joint arrangement to the steering wheel. The input-shaft therefore needs to rotate through an angle typically one to  
15 two revolutions either side of the on-centre steering position. The input-shaft is at least partially surrounded by the fixed housing of the steering gear. It is a requirement of the electric power steering servo system to accurately measure the continuously varying torque in this rotating shaft. Conventionally torque applied to the shaft causes it to angularly deflect, such deflection causing one part of the  
20 shaft to angularly displace with respect to another part, and this displacement is sensed to provide a measurement of this torque.

The sensing means needs to allow for rotation of the shaft within the housing, usually employing non-contact or mechanical transmission means. Non-contact  
25 means include magnetic devices such as magnetostrictive or variable reluctance couplings. Mechanical means include slidably connected potentiometers or other indicating devices.

To improve the accuracy of such sensing means a torsion bar, which may be more  
30 torsionally compliant than the shaft, is inserted in series with the shaft. When torque is applied the torsion bar deflects causing an increased angular displacement which allows the use of less sensitive or less accurate sensing means.

Generally, the use of a torsion bar requires the use of a torque limiting device to prevent failure of the torsion bar when unavoidable torque overload conditions occur.

5

Such torque limiting devices are well known in the art of vehicle steering, and will therefore not be described in this specification.

The prior art which is most closely related to that of the present invention is U.S. Patent 4,907,460 (Taniguchi, et.al.) and U.S. Patent 4,881,414 (Setaka, et.al.) which shows sensors employing magnetic coupling for measuring torque.

The essence of the present invention resides in the provision of an optical displacement sensing means providing a light signal output which is conveyed to the fixed housing via an optical transmission means. The optical transmission means comprises fiber optical cables, which are flexible, thus are able to be formed as a fiber optical clockspring, which allows relative rotation of the shaft and housing. The advantages of such a construction over that disclosed in U.S. Patents 4,907,460 and 4,881,414 may arise as one or more of the following:

20

Firstly, the optical displacement sensing means is not prone to disruption from external electrical or magnetic fields as is generally present in vehicles.

Secondly, the optical displacement sensing means can measure a smaller displacement than magnetic or mechanical methods without unacceptably high manufacturing accuracy or cost. The ability to sense a small displacement allows the torsion bar to be eliminated or made sufficiently stiff so that it can be used without torque limited devices. This allows simpler and cheaper construction of the transducer.

30

Thirdly, the optical transmission means provides a simple method of transmitting the signal output from the rotating shaft to the housing, without interference from

external electric or magnetic fields. Mounting the optical-electric converter means on the rotating shaft would require electrical signal transmission from the shaft to

- 5 the housing, which would be prone to mechanical or electrical failure or electrical and magnetic interference.

### DISCLOSURE OF INVENTION

- 10 One aspect of the present invention consists in a transducer for measuring torque in a rotating shaft, the shaft at least partially surrounded by a fixed housing, characterised in that the transducer comprises an optical displacement sensing means, an optical transmission means, and an optical-electric converter means, the optical displacement sensing means residing on the shaft and modulating a
- 15 light signal input to provide a light signal output relating to the magnitude of torque, the light signal output communicated to the optical-electric converter means via the optical transmission means, the optical transmission means comprising an optical clock spring, the optical-electric converter means either mounted to the housing or external to the housing, the optical clock spring comprising one or more flexible
- 20 fiber optical cables, each cable arranged to be of sufficient length to allow the measurement of the magnitude of torque over a predetermined angular range of rotation of the shaft, and the optical-electric converter means thereby providing an electrical output signal relating to the magnitude of the torque in the shaft.
- 25 It is preferred that the housing substantially surrounds the shaft and an annular space exists there between enclosing the clockspring. In one embodiment the clockspring is wound into a single coil that partly winds or unwinds depending on the direction of rotation of the shaft. In another embodiment the clockspring is in the form of two coils wound in opposite directions and, for a given direction of
- 30 rotation of the shaft, one coil winds and the other unwinds.

- In one embodiment, the optical displacement sensing means comprises a torsionally compliant member that produces an angular or linear displacement between first and second positions on the shaft dependent on the magnitude of torque in the shaft, first and second link members are attached to the shaft at the first and second positions respectively, wherein the displacement results in a variation of distance or angle between one surface attached to the first link member and another surface attached to the second link member, the variation modulating the intensity of the light signal output compared to the light signal input. Preferably, one of the surfaces is reflective and the variation modulates the intensity of the light signal output by changing the amount of reflected light collected by the one or more fiber optical cables.
- 15 In another embodiment, the optical displacement sensing means comprises a torsionally compliant member, and torque applied to the member results in strain in the compliant member, and a portion of one or more of fiber optical cables rigidly attached to the compliant member is thereby also strained. Preferably, the strain elongates a grating applied to the strained section of the cable, comprising
- 20 repetitively spaced variations in refractive index or cable dimensions, resulting in a change in frequency, delay time or phase of light signal output compared to the light signal input. Alternatively, the strain elongates a cavity, comprising two partially or completely reflecting surfaces substantially parallel to each other and spaced by a given distance, included in the strained portion of the cable, resulting
- 25 in a change in frequency, delay time or phase of light signal output compared to light signal input.

- In still another embodiment, the optical displacement sensing means comprises a torsionally compliant member that produces an angular or linear displacement between first and second positions on the shaft depending on torque, first and second link members are attached to the shaft at the first and second positions respectively and are interconnected by a beam, wherein the displacement produces a variation of curvature of the beam dependent on the magnitude of
- 30



torque. The variation of curvature results in change of shape of the one or more fiber optical cables attached to the surface of the beam, thereby modulating the intensity of the light signal output compared to the light signal input.

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In one embodiment the optical-electrical converter means comprises a light source, which generates the light signal input.

In another embodiment, the clockspring also comprises one of more electrical  
10 conductors used to power a light source rotating with the shaft, providing the light signal input.

### BRIEF DESCRIPTION OF DRAWINGS

15 The present invention will now be described by way of example with reference to the accompanying drawings, in which:

Fig.1 is a block diagram showing the various parts of the invention;

Fig.2 is a view of a shaft;

20 Fig.3 is a view of a shaft including a torsion bar;

Fig.4 is a sectional view of Fig.3 on plane AA showing measured dimension "d" for one embodiment of the invention;

Fig.5 is a close up view of one portion of Fig.4;

Fig.6 is an overall sectioned view of the same embodiment;

25 Fig.7 is a sectional view of Fig. 6 on plane BB showing details of the optical clockspring;

Fig.8 is a sectional view similar to Fig.6 of a second embodiment of the invention;

Fig.9 is a close-up view of Fig.8 showing the layout of the fiber optical cables on the torsion bar;

30 Fig.10 is a view of a third embodiment of the invention;

Fig.11 is a sectional view of Fig. 10 on plane CC showing radius "r",

Fig.12 is a perspective view of Fig. 11,

Fig.13 is a view of another embodiment of the fiber optical clockspring,

- Fig.14 is a sectional view of Fig. 13 on plane DD;  
Fig.15 is a block diagram similar to Fig. 1, showing another embodiment of the optical-electric converter means; and  
5 Fig.16 is a block diagram similar to Fig. 1, showing still another embodiment of the optical-electric converter means.

### MODE OF CARRYING OUT INVENTION

- 10 Fig. 1 shows a block diagram of the transducer. A light signal input is modulated by the optical displacement sensing means, which provides a light signal output. This output is transmitted across the interface between the rotating shaft and fixed housing to the optical-electric converter by an optical transmission means, being a fiber optical clockspring. The converter converts the light signal output to an  
15 electrical output signal, which provides a measure of the torque applied to the shaft.

- Referring to Figs. 2, 3 and 4, the torque applied to shaft 1 produces an angular deflection of this shaft and hence a displacement "d" over a distance "L" on its  
20 periphery. This displacement can be generated directly on the shaft, as shown in Fig.2, or generated on an apparatus such as a torsion bar assembly, shown in Fig. 3. Fig. 3 shows a torsion bar assembly comprising torsion bar 2 in series with shaft 1 with a torsional compliance different to shaft 1, link 3 attached to one end of torsion bar 2 and link 4 attached to the other end of torsion bar 2. Referring to  
25 Fig. 4, application of torque to the assembly results in an angular deflection of the torsion bar and a resultant change in dimension "d".

- Referring to Fig. 5, an application of torque to the torsion bar assembly results in a displacement "d" between links 3 and 4 which is measured with an optical  
30 displacement sensing means. Optical fiber 5 is fixed to link 4 and provides a light signal input that illuminates an area "f" on link 3. The size of area "f" depends on the distance "e" between links 3 and 4 which varies as a function of torque applied to the torsion bar assembly. Optical fiber 6 receives light reflected from area "g"

on link 3. The size of area "g" likewise depends on distance "e". Area "h" on link 3 is the area common to areas "f" and "g" and represents the area wherein light emitted from fiber 5 is reflected from link 3 and collected by fiber 6. Thus the optical signal output, being the amount of light collected by fiber 6, varies as a function of torque. An example of this method can be found in "In-cylinder Fiber-Optic Pressure Sensor for Engine Monitoring and Control", Thomas Poorman, Sergey Kalashnikov and Marek Wlodarczyk, published in ICE Vol 26-2 1996 Spring Technical Conference, ASME 1996.

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Referring to Fig. 6 and Fig. 7, the torsion bar assembly, comprising torsion bar 2 and links 3 and 4, is supported in a housing 9 and 10 by bearings 11 and 12 and is able to rotate with respect to the housing. A fiber optic clockspring, comprising fixed part 14 and rotating part 13 is attached to the housing and shaft respectively. Fiber optic cables 8 are attached at one end to link 3 and the other end to fixed part 14 in a coiled arrangement with sufficient space between parts 13 and 14 to allow a predetermined range of angular rotation. Depending on direction of rotation, this results in winding or unwinding of the coils. The fixed ends of the fiber optical cables are connected via optical link 15 to the optical-electric converter 7. This link can be an extension of the cables or additional optical fiber cables. The optical-electric converter converts the optical signal output to an electrical output signal relating to the magnitude of torque applied to the shaft.

20

Referring to Fig. 8 and Fig. 9, a second embodiment of the invention measures the strain in the torsion bar 2 directly. Fig. 9 shows the ends of fiber optical cables 24 and 25 which are firmly attached to the torsion bar such that respective areas 26 and 27 experience the strain generated in torsion bar 2 by the application of torque to shaft 1. Preferably areas 26 and 27 are aligned with the axes of principal strain of the surface of torsion bar 2. These areas comprise gratings or cavities which are sensitive to strain, such that light passing down the cables is reflected back up the cables with a resultant change in frequency, time delay or phase change as a function of strain. Details of such gratings and cavities can be found in the publication "Fiber Optic Sensors" by Eric Udd, published by SPIE

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International Society for Optical Engineering as volume CR44, ISBN 0-8194-0980-

4. Shaft 1 and torsion bar 2 are supported in housing 16 and 17 by bearings 18 and 19 and, as before, are able to rotate with respect to the housing. A fiber optic  
5 clockspring, comprising fixed part 23 and rotating part 22 is attached to the shaft and housing. Fiber optic cables 24 and 25 are attached at one end to the fixed part 23 and at the other end to the rotating part in a coiled arrangement with sufficient space between parts 23 and 22 to allow a predetermined range of angular rotation.

10

Depending on direction of rotation, this results in winding or unwinding of the coils. The fixed ends of the fiber optical cables are connected via optical link 21 to the optical-electric converter 20. This link can be an extension of the cables or additional optical fiber cables. The optical-electric converter converts the optical  
15 signal output to an electrical output signal relating to the magnitude of torque applied to the shaft.

Figs. 10, 11 and 12 show a third embodiment of the invention. The torsion bar assembly comprises torsion bar 2, link 28 attached to one end of the torsion bar  
20 and link 29 attached to the other end of the torsion bar. Flexible member 40 is attached to one end of link 28. Pin 30 connects link 29 and flexible member 40. Application of torque to the assembly results in angular displacement of link 29 with respect to link 28. This angular displacement is converted into a change in radius of curvature "r" of flexible member 40. The fiber optical cables 5 are  
25 attached to flexible member 40 in such a manner that light passing through them is attenuated by an amount relating to the radius of curvature of flexible member 40. Thus the cables convert an optical signal input to an optical signal output which is a function of torque in the shaft. The method of preparing and attaching the cables can be understood by reference to International Application WO 94/29671.  
30 The torsion bar assembly is supported in housing 31 and 32 by bearings 36 and 37 and is able to rotate with respect to the housing. A fiber optic clockspring, comprising fixed part 34 and rotating part 33 is attached to the housing and shaft respectively. Fiber optic cables 5 are formed in a loop, with the looped ends

attached to flexible member 40 and the other ends to the fixed part 34 in a coiled arrangement with sufficient space between parts 33 and 34 to allow a predetermined range of angular rotation. Depending on direction of rotation, this results in a winding or unwinding of the coils. The fixed ends of the fiber optical cables are connected via optical link 38 to the optical-electric converter 39. This link can be an extension of the cables or additional optical fiber cables. The optical-electric converter converts the optical signal output to an electrical output signal relating to the magnitude of torque applied to the shaft.

Figs. 13 and Fig. 14 are similar to Fig. 6 and Fig. 7 showing another embodiment of the fiber optical clockspring. The torsion bar assembly and optical displacement sensing means are essentially the same as shown in Fig. 6 and Fig. 7. However, the fiber optical clockspring comprises an annular space in which the fiber optic cables 41 have a U shaped portion 45 that will move at an angular speed less than that of rotating shaft 1.

Fiber optic cables 41 are unwound from fixed member 44 and wound onto the rotating member 43 in the opposite direction of winding for one direction of rotation of the rotating member. For the other direction of rotation, the cable is unwound from rotating member 43 and wound onto fixed member 44 in the opposite direction of winding. A "C" shaped cable guide 42 may be used, either driven by the movement of the cables or by the relative rotation between the rotating and non-rotating parts. This arrangement reduces noise generated by sliding of the fiber optical cable coils compared to the arrangement shown in Fig. 6 and Fig. 7.

Referring to Fig. 15, the optical-electric converter may include a light source that provides the light signal input to the rotating optical displacement sensing means via the optical transmission means.

Referring to Fig. 16, in another embodiment the light source is included as part of the rotating optical displacement sensing means. Electrical power may be

supplied via electrically conductive elements incorporated in the optical transmission means.

- 5 It will be appreciated by persons skilled in the art that numerous variations and/or modifications may be made to the invention as shown in the specific embodiments without departing from the spirit or the scope of the invention as broadly described. The present embodiments are, therefore, to be considered in all respects as illustrative and not restrictive.

**WE CLAIM:**

1. A transducer for measuring torque in a rotating shaft, the shaft at least  
5 partially surrounded by a fixed housing, characterised in that the transducer comprises an optical displacement sensing means, an optical transmission means, and an optical-electric converter means, the optical displacement sensing means residing on the shaft and modulating a light signal input to provide a light signal output relating to the magnitude of torque, the light  
10 signal output communicated to the optical-electric converter means via the optical transmission means, the optical transmission means comprising an optical clock spring, the optical-electric converter means either mounted to the housing or external to the housing, the optical clock spring comprising one or more flexible fiber optical cables, each cable arranged to be of  
15 sufficient length to allow the measurement of the magnitude of torque over a predetermined angular range of rotation of the shaft and the optical-electric converter means thereby providing an electrical output signal relating to the magnitude of the torque in the shaft.
2. A transducer for measuring torque in a rotating shaft as claimed in Claim 1,  
20 wherein the housing substantially surrounds the shaft and an annular space exists there between enclosing the clockspring.
3. A transducer for measuring torque in a rotating shaft as claimed in Claim 2,  
wherein the clockspring is wound into a single coil that partly winds or unwinds depending on the direction of rotation of the shaft.
- 25 4. A transducer for measuring torque in a rotating shaft as claimed in Claim 2,  
wherein the clockspring is in the form of two coils wound in opposite directions and, for a given direction of rotation of the shaft, one coil winds and the other unwinds.

5. A transducer for measuring torque in a rotating shaft as claimed in Claim 1,  
wherein the optical displacement sensing means comprises a torsionally  
compliant member that produces an angular or linear displacement between  
first and second positions on the shaft dependent on the magnitude of torque  
in the shaft.
6. A transducer for measuring torque in a rotating shaft as claimed in Claim 5,  
wherein first and second link members are attached to the shaft at the first  
and second positions respectively, the displacement resulting in a variation in  
distance or angle between one surface attached the first link and another  
surface attached to the second link, the variation modulating the intensity of  
the light signal output compared to the light signal input.
7. A transducer for measuring torque in a rotating shaft as claimed in Claim 6,  
wherein one of the surfaces is reflective and modulation of the intensity of the  
light signal output is achieved by changing the amount of reflected light  
collected by the one or more fiber optical cables.
8. A transducer for measuring torque in a rotating shaft as claimed in Claim 5,  
wherein the displacement results in strain in the compliant member, a portion  
of one or more of the fiber optical cables rigidly attached to the compliant  
member is thereby also strained, thereby resulting in a change in frequency,  
delay time or phase of the light signal output compared to the light signal  
input.
9. A transducer for measuring torque in a rotating shaft as claimed in Claim 8,  
wherein the strain elongates a grating applied to the strained portion of the  
one or more fiber optical cables, comprising repetitively spaced variations in  
refractive index or cable dimensions.



10. A transducer for measuring torque in a rotating shaft as claimed in Claim 8,  
wherein the strain elongates a cavity included in the strained portion of the  
one or more fiber optical cables, comprising of two partially or completely  
reflecting surfaces substantially parallel to each other and spaced by a given  
distance.
11. A transducer for measuring torque in a rotating shaft as claimed in Claim 5,  
wherein first and second link members are attached to the shaft at the first  
and second positions respectively and are interconnected by a beam, the  
displacement producing a variation of curvature of the beam dependent on  
the magnitude of torque, the variation of curvature resulting in change of  
shape of the one or more fiber optical cables attached to the surface of the  
beam, thereby modulating the intensity of the light signal output compared to  
the light signal input.
12. A transducer for measuring torque in a rotating shaft as claimed in Claim 1,  
wherein the optical-electric converter means comprises a light source, which  
generates the light signal input.
13. A transducer for measuring torque in a rotating shaft as claimed in Claim 1,  
wherein the clockspring also comprises one or more electrical conductors.
14. A transducer for measuring torque in a rotating shaft as claimed in Claim 13,  
wherein the electrical conductors are used to power a light source rotating  
with the shaft, providing the light signal input.

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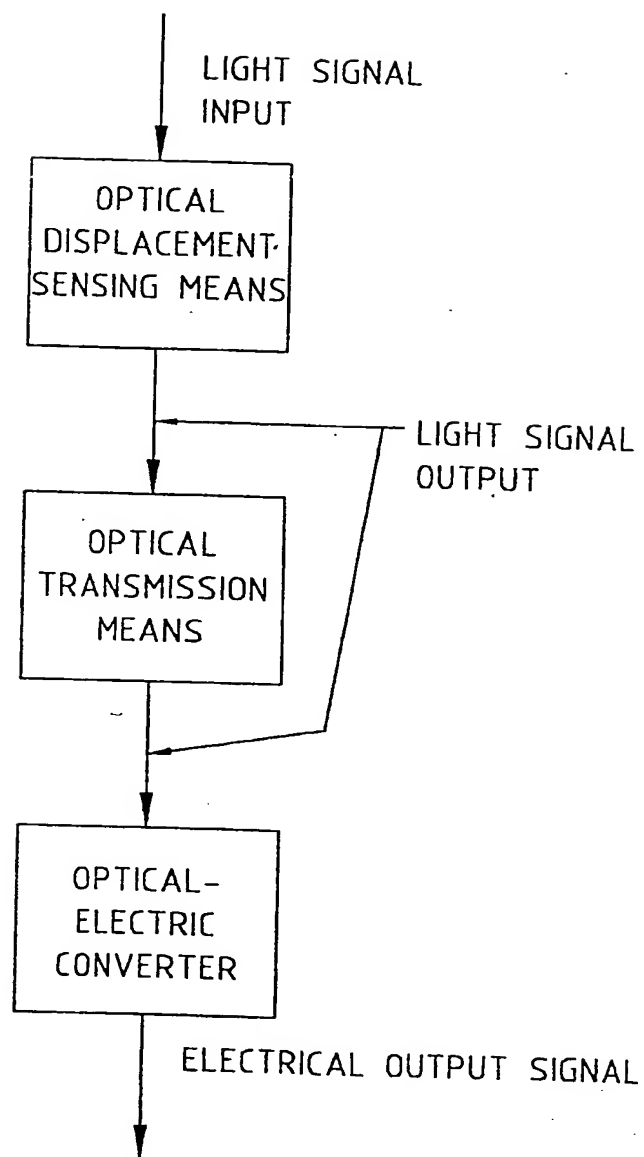


Fig 1

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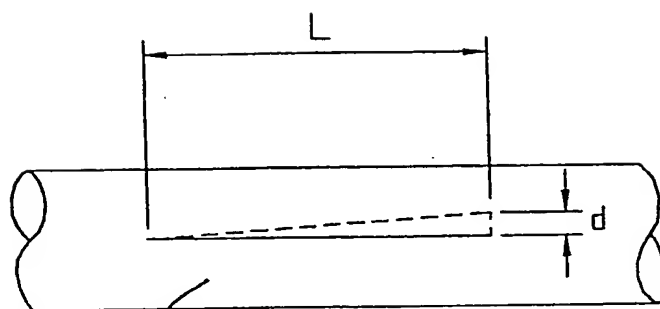


Fig 2

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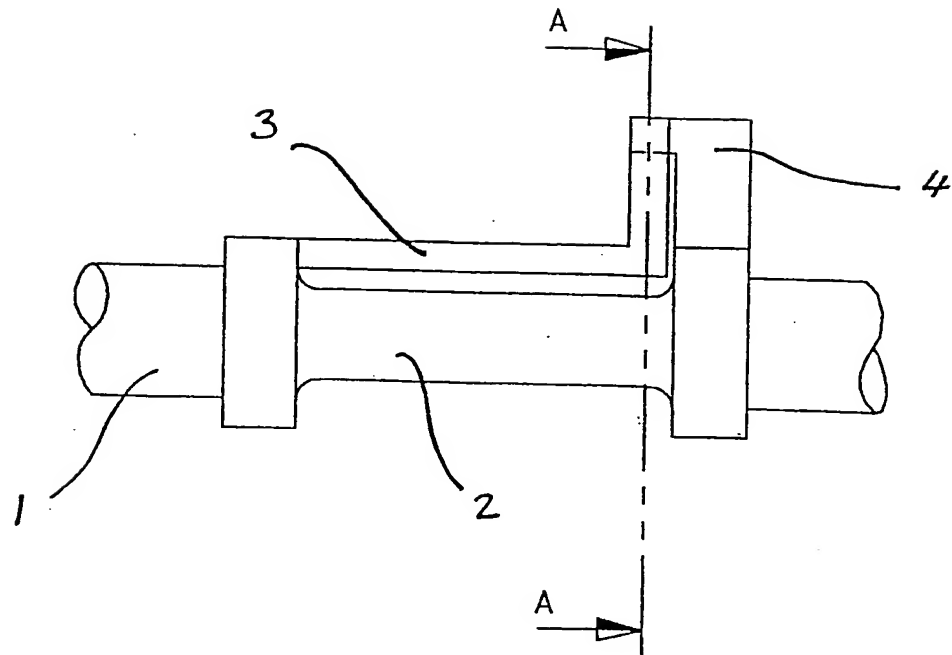


Fig 3

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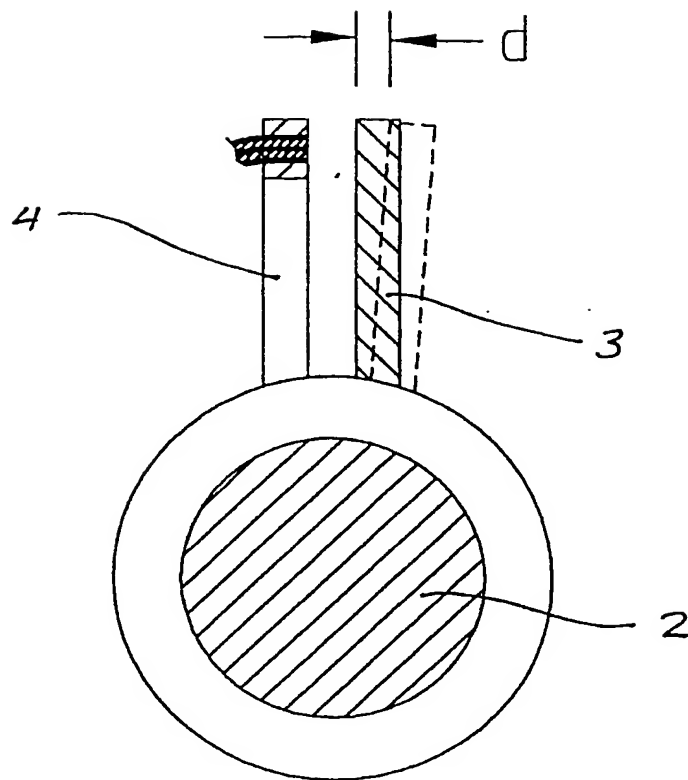


Fig 4

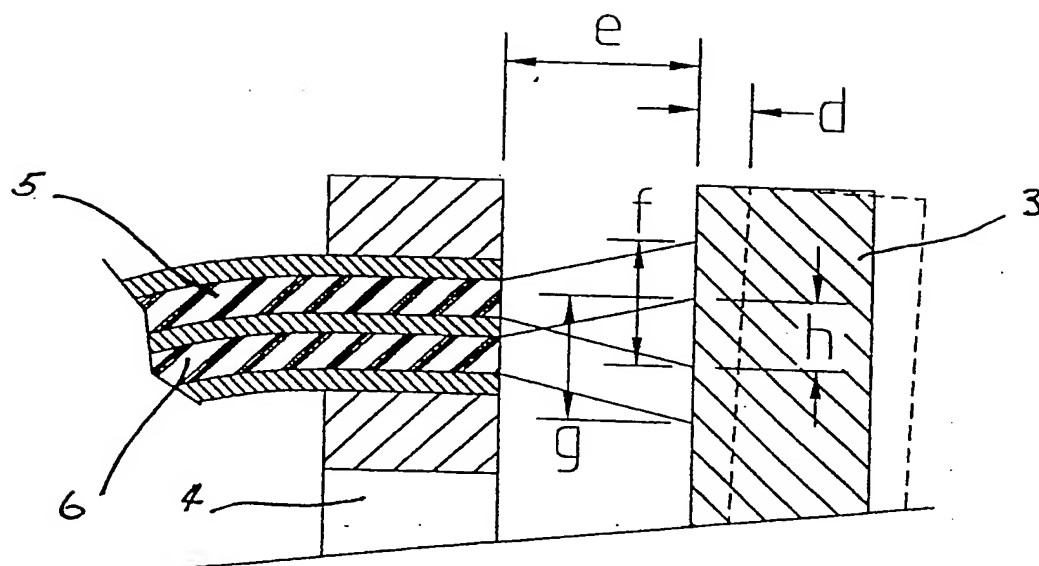


Fig 5

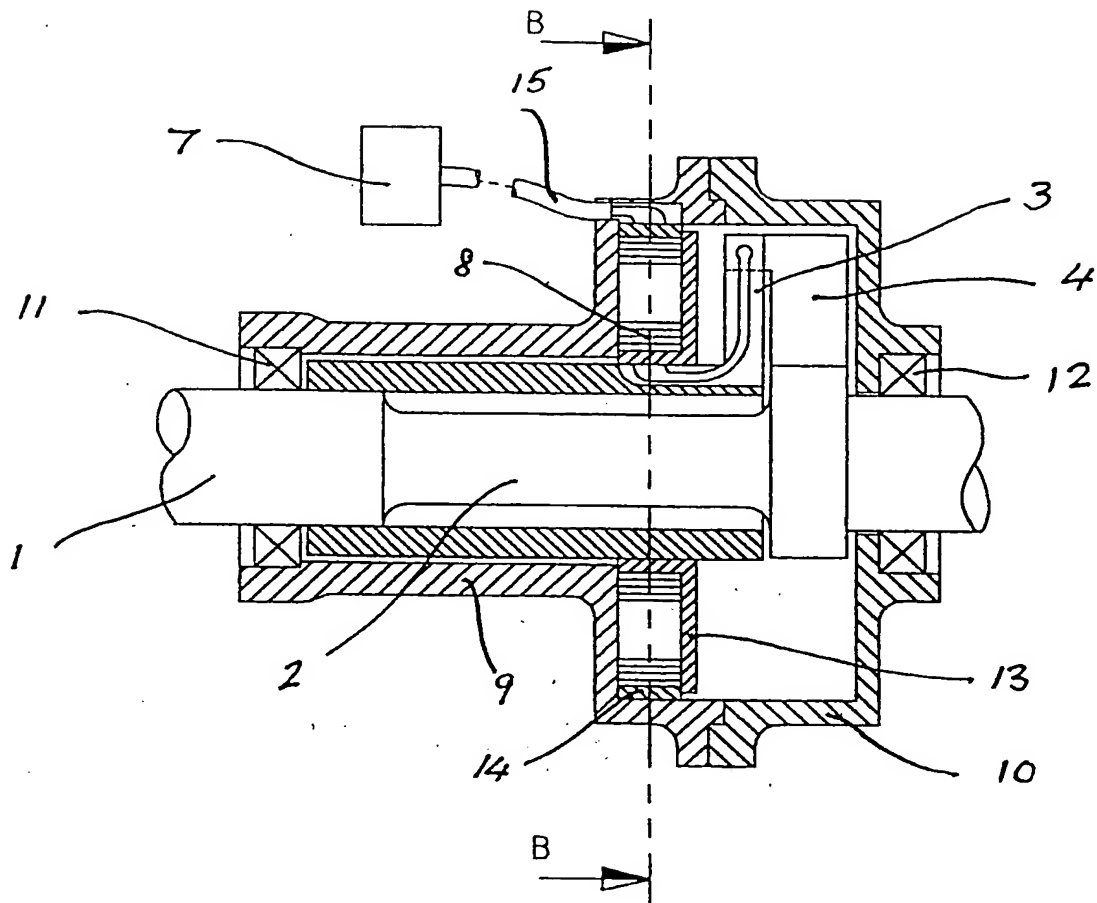


Fig 6

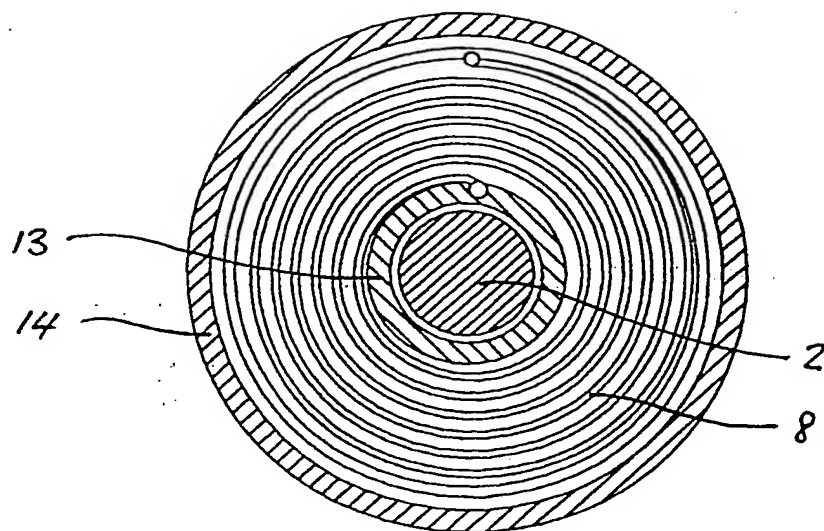


Fig 7



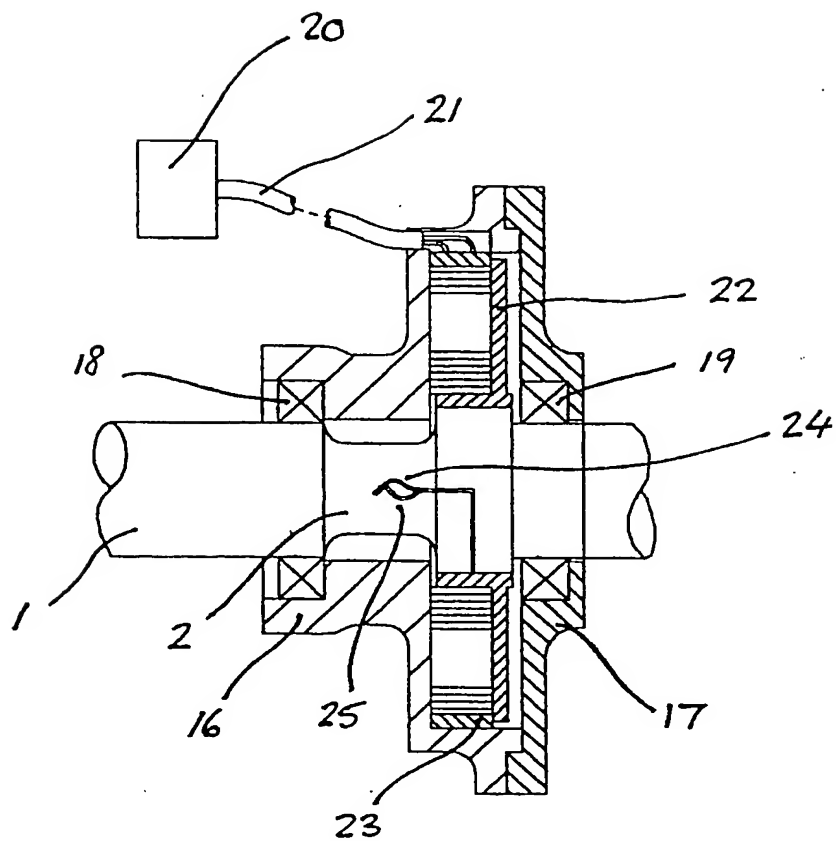


Fig 8

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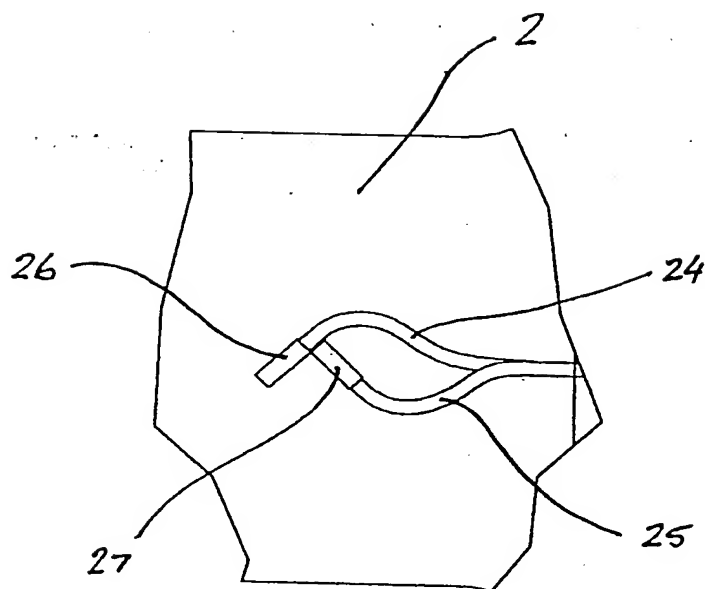


Fig 9

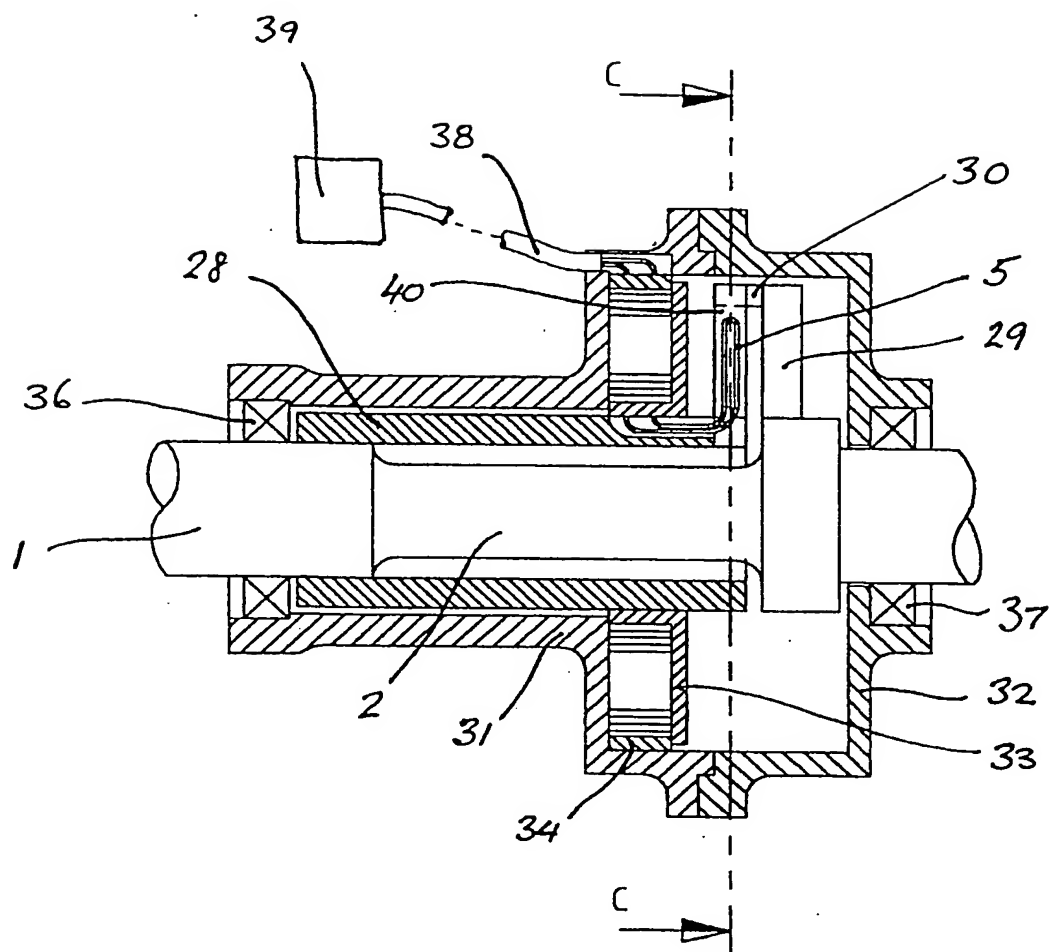


Fig 10

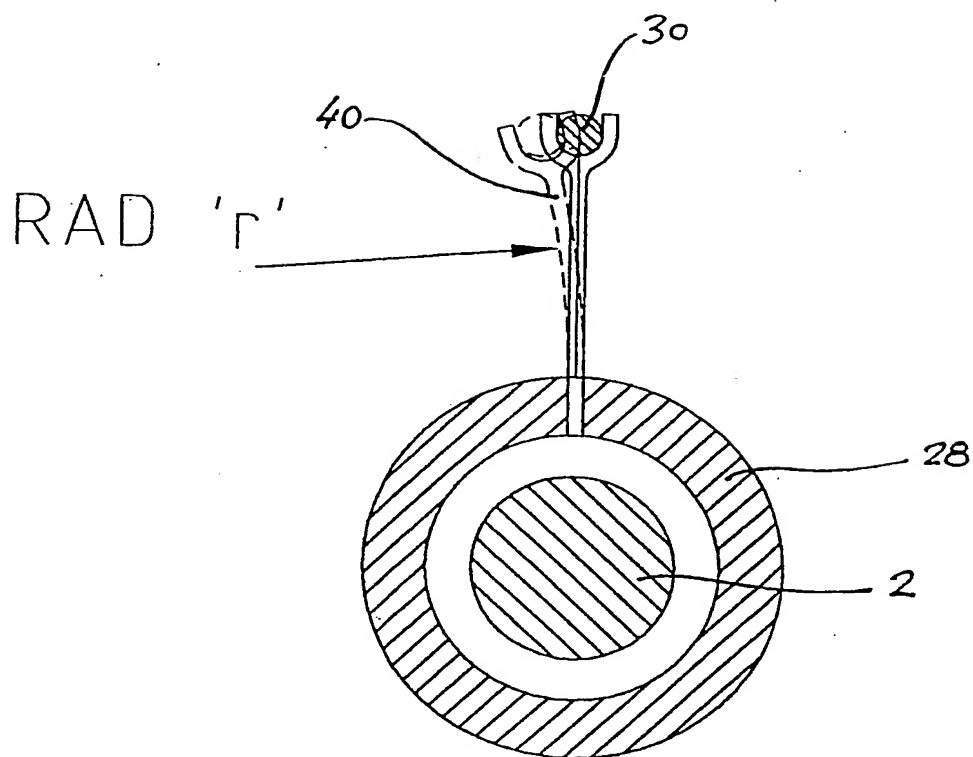


Fig 11

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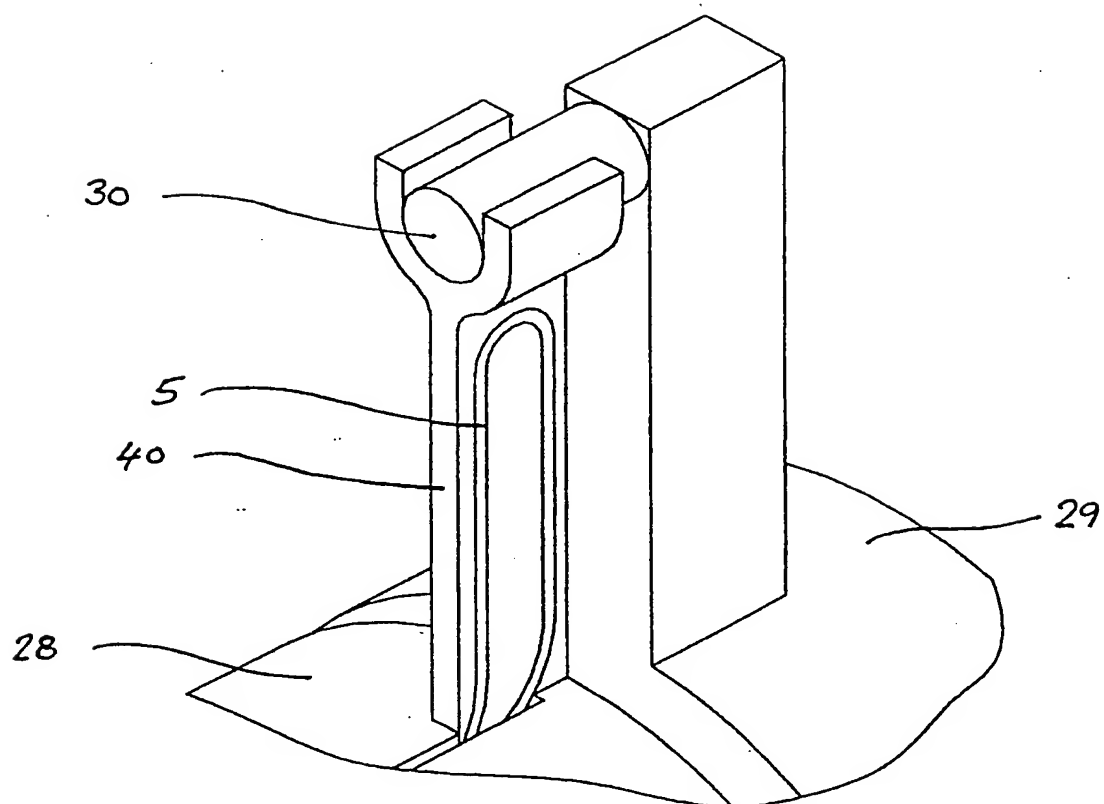


Fig 12

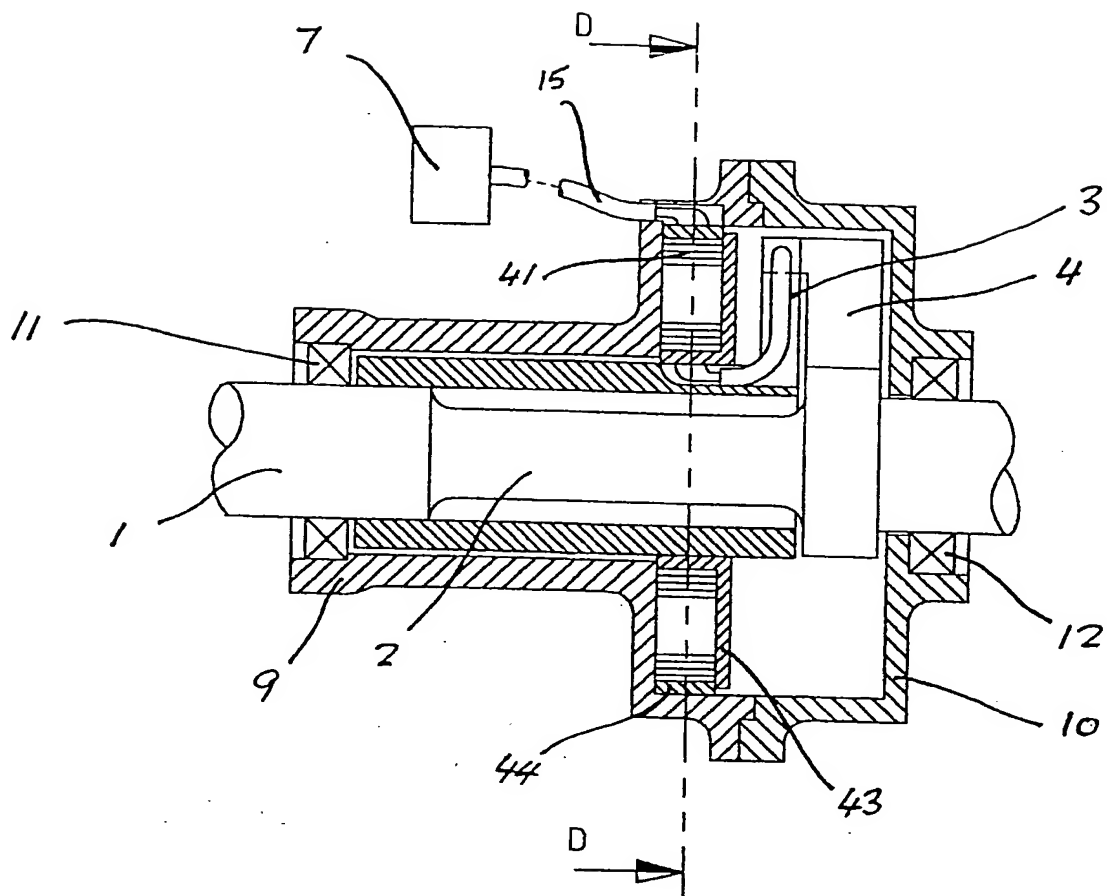


Fig 13

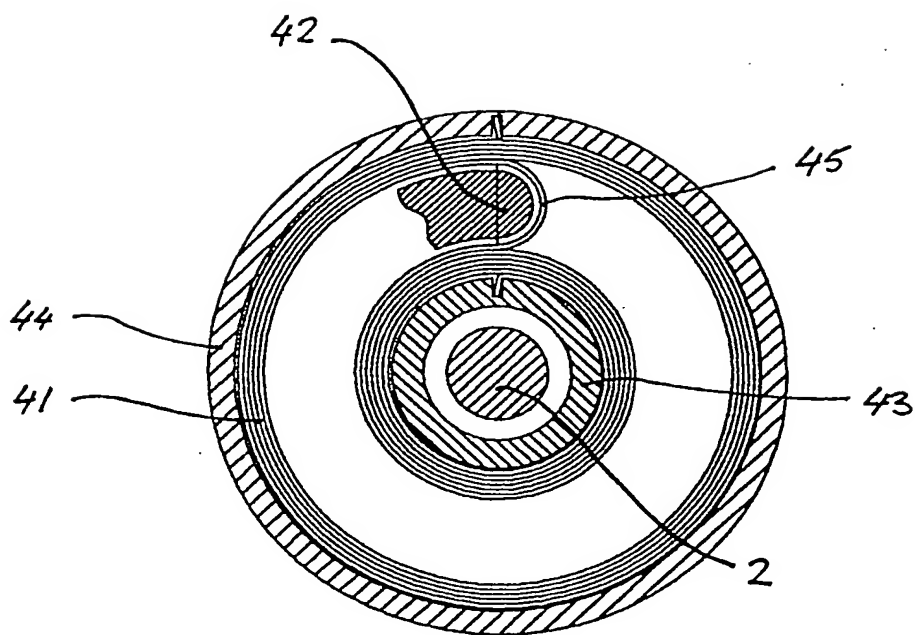


Fig 14

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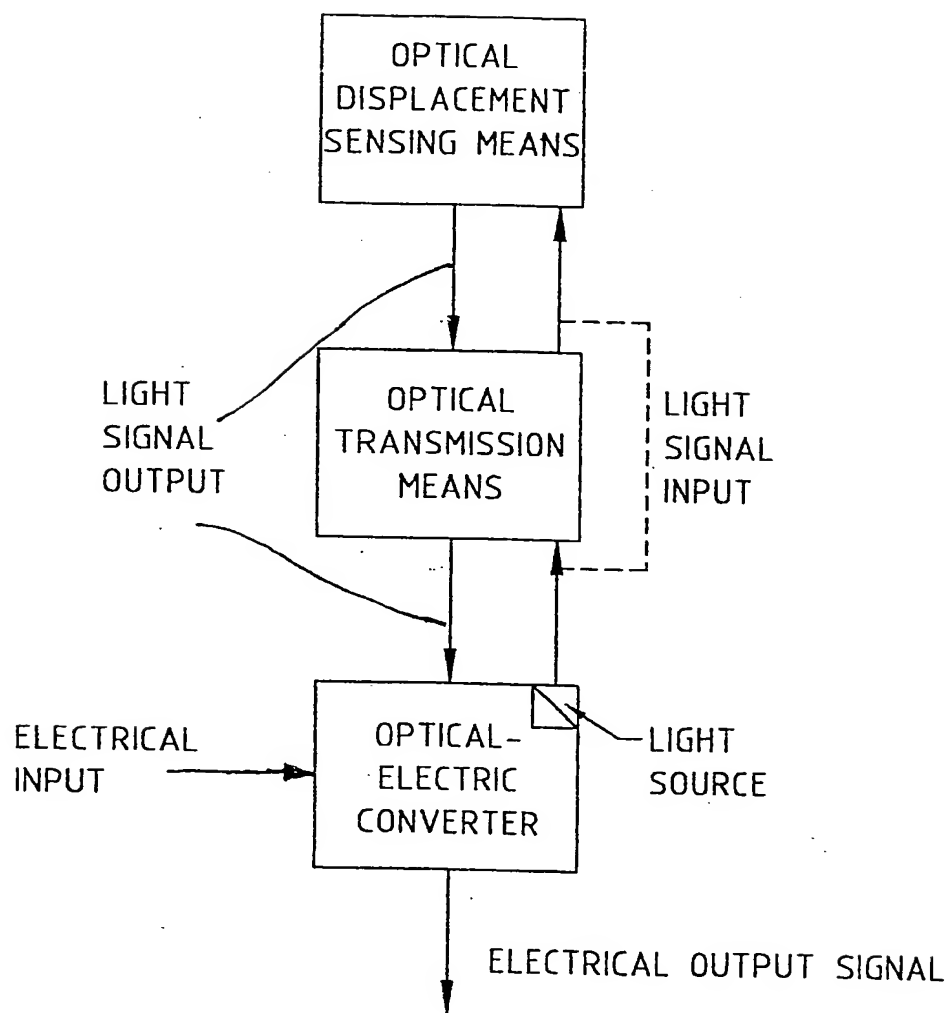


Fig 15



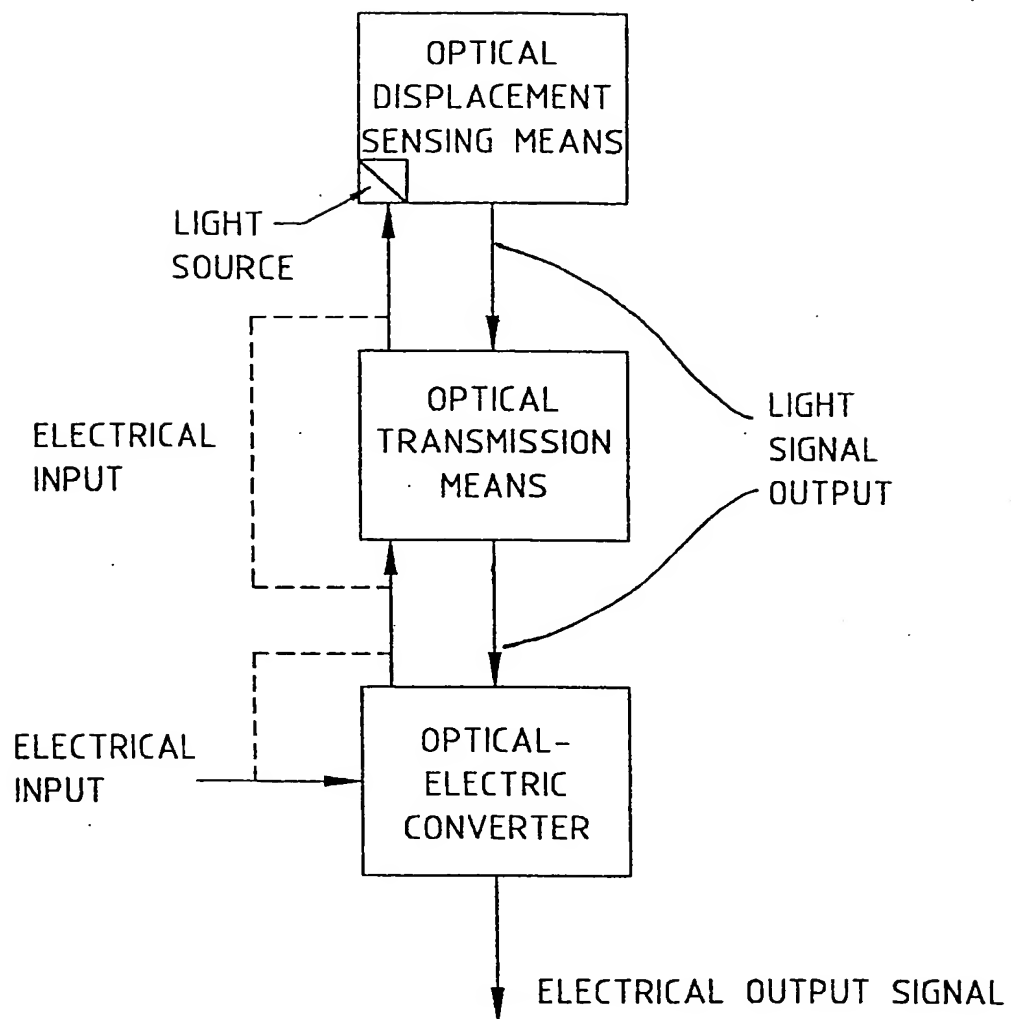


Fig 16

## INTERNATIONAL SEARCH REPORT

International application No.  
PCT/AU 98/00575

**A. CLASSIFICATION OF SUBJECT MATTER**

Int Cl<sup>6</sup>: G01L 3/12, 3/08

According to International Patent Classification (IPC) or to both national classification and IPC

**B. FIELDS SEARCHED**

Minimum documentation searched (classification system followed by classification symbols)  
G01L 3/ALL, G01L 5/ALL

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched  
AU: IPC as above

Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)  
WPAT: } (OPTIC: OR LIGHT:) AND (FIBR: OR FIBER:) (   
JPIO: }

**C. DOCUMENTS CONSIDERED TO BE RELEVANT**

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
A	Patent Abstracts of Japan, P-948, page 111, JP 1-184430 A (KOYO SEIKO CO LTD) 24 July 1989 Abstract	
A	US 4637264 A (TAKAHASHI et al.) 20 January 1987 Entire document	
A	US 5369583 A (HAZELDEN) 29 November 1994 Entire document	

☒ Further documents are listed in the  
continuation of Box C

☒ See patent family annex

## \* Special categories of cited documents:

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Date of the actual completion of the international search  
14 September 1998

Date of mailing of the international search report  
22 SEP 1998

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## INTERNATIONAL SEARCH REPORT

International application No.

PCT/AU 98/00575

C (Continuation). DOCUMENTS CONSIDERED TO BE RELEVANT		
Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
A	EP 185619 A (BATTLE MEMORIAL INSTITUTE) 25 June 1986 Entire document	

### Information on patent family members

International application No.  
**PCT/AU 98/00575**

This Annex lists the known "A" publication level patent family members relating to the patent documents cited in the above-mentioned international search report. The Australian Patent Office is in no way liable for these particulars which are merely given for the purpose of information.

Patent Document Cited in Search Report				Patent Family Member			
US	4637264	CA	1231254	DE	3517889	FR	2564586
		GB	2162309	JP	60243532		
US	5369583	DE	69306431	EP	555987	JP	5281060
EP	185619	CA	1249645	JP	61184407	US	4641027